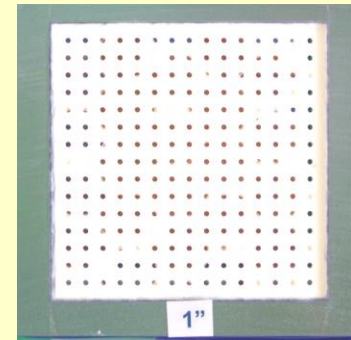
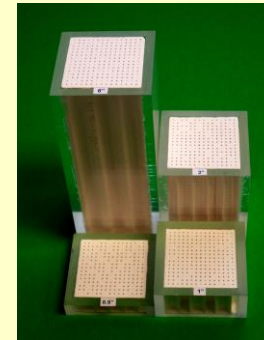
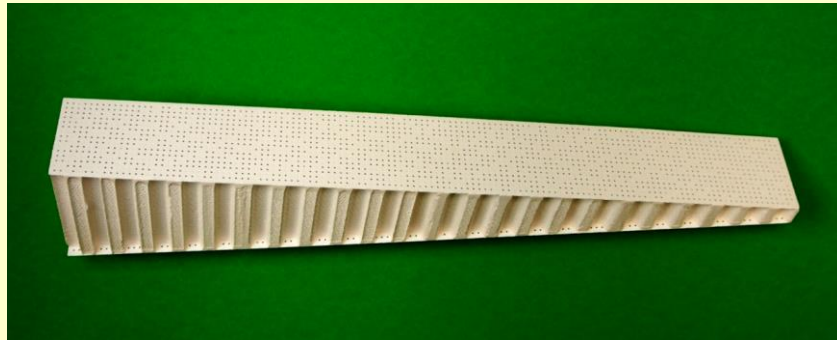




# Compact, Lightweight, Ceramic Matrix Composite (CMC) Based Acoustic Liners for Reducing Subsonic Jet Aircraft Engine Noise

J. Douglas Kiser and Joseph E. Grady, *Ceramic and Polymer Composites Branch*  
Christopher J. Miller and Lennart S. Hultgren, *Acoustics Branch*  
NASA Glenn Research Center, Cleveland, OH

Michael G. Jones, *Structural Acoustics Branch*  
NASA Langley Research Center, Hampton, VA



**HTCMC - 9:**  
**9<sup>th</sup> International Conference on High Temperature  
Ceramic Matrix Composites**

***June 26 - July 1, 2016, Toronto, Canada***

**Research Supported by the NASA Fundamental Aeronautics Program**



# Compact, Lightweight, CMC Based Acoustic Liners for Reducing Subsonic Jet Aircraft Engine Noise

## Overview

- Reduction of aircraft noise, with emphasis on reducing core noise
- Acoustic liner for reducing core noise—considerations and goals
- Acoustic absorption via Quarter Wavelength Resonators
- CMC acoustic liners that can provide broadband absorption
  - advantages of oxide/oxide CMC liners
  - liner concepts
  - test articles
  - results
- Potential future efforts



# Need to Reduce Perceived Community Noise Attributable to Aircraft

## Background / Problem





# NASA is Working With Other Organizations to Reduce Aircraft Noise, NOx Emissions, and Fuel Burn

## NASA Subsonic Transport System Level Measures of Success

v2016.1

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	Mid Term 2025-2035	Far Term beyond 2035
<b>Noise</b> (cum below Stage 4)	↓ 22 - 32 dB	↓ 32 - 42 dB	↓ 42 - 52 dB
<b>LTO NOx Emissions</b> (below CAEP 6)	70 - 75%	80%	> 80%
<b>Cruise NOx Emissions</b> (rel. to 2005 best in class)	65 - 70%	80%	> 80%
<b>Aircraft Fuel/Energy Consumption</b> (rel. to 2005 best in class)	40 - 50%	50 - 60%	60 - 80%



Evolutionary



Revolutionary

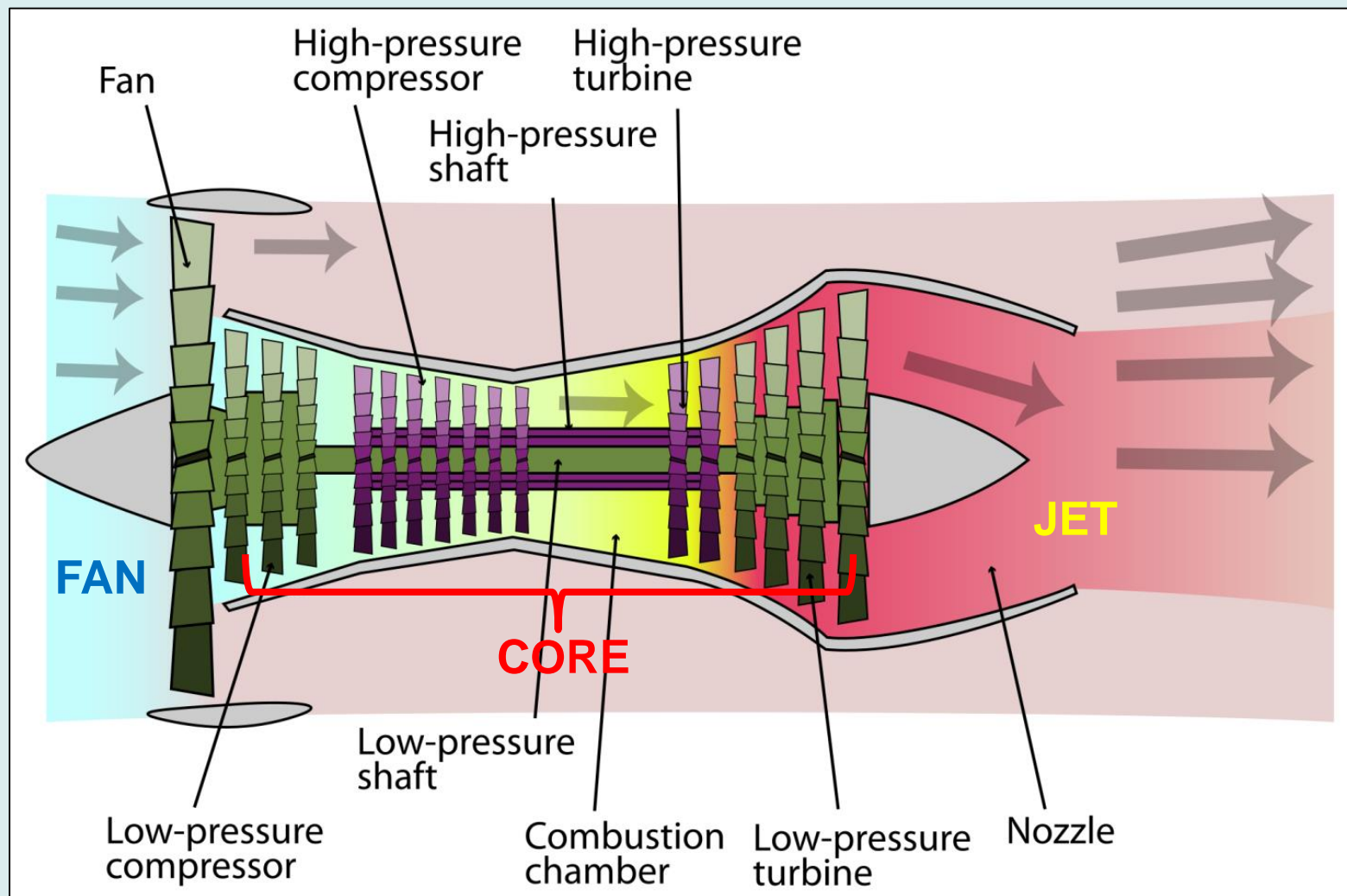


Transformational

**It will take a combination of noise reduction approaches to achieve these goals**



# Turbofan Jet Engine Schematic



**Contributions to Engine Noise: Fan, Jet, Core**



# Need for Reducing Jet Engine Core Noise

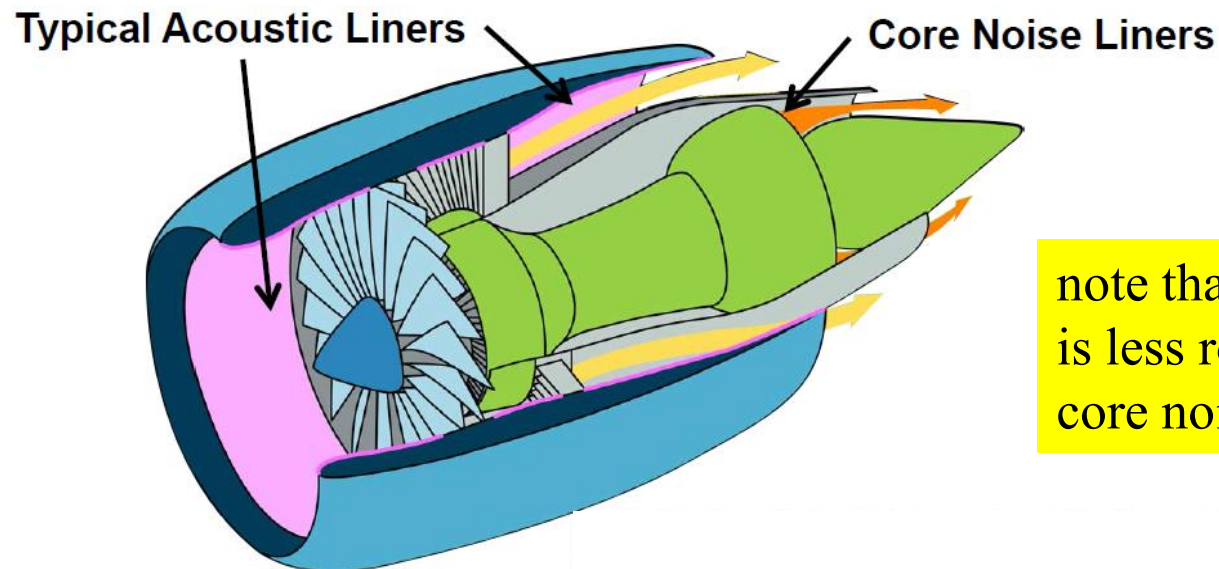
## Background / Problem

- As fan and jet noise components are reduced, the importance of core (combustor, turbine) noise increases.
- Expecting increased core noise levels as aircraft engines evolve over the next decade.
- Core noise could limit the total noise reduction potential of new ultra-high bypass systems.



## Addressing the Issue of Core Noise

- NASA has investigated core noise in a task [\(Ref. 1-5\)](#) focused on:
  - understanding the nature of core noise and its level of importance (contribution to overall engine noise), and
  - means of reducing core noise.
- This CMC acoustic liner development effort [\(Ref. 6\)](#) was performed to support that task.



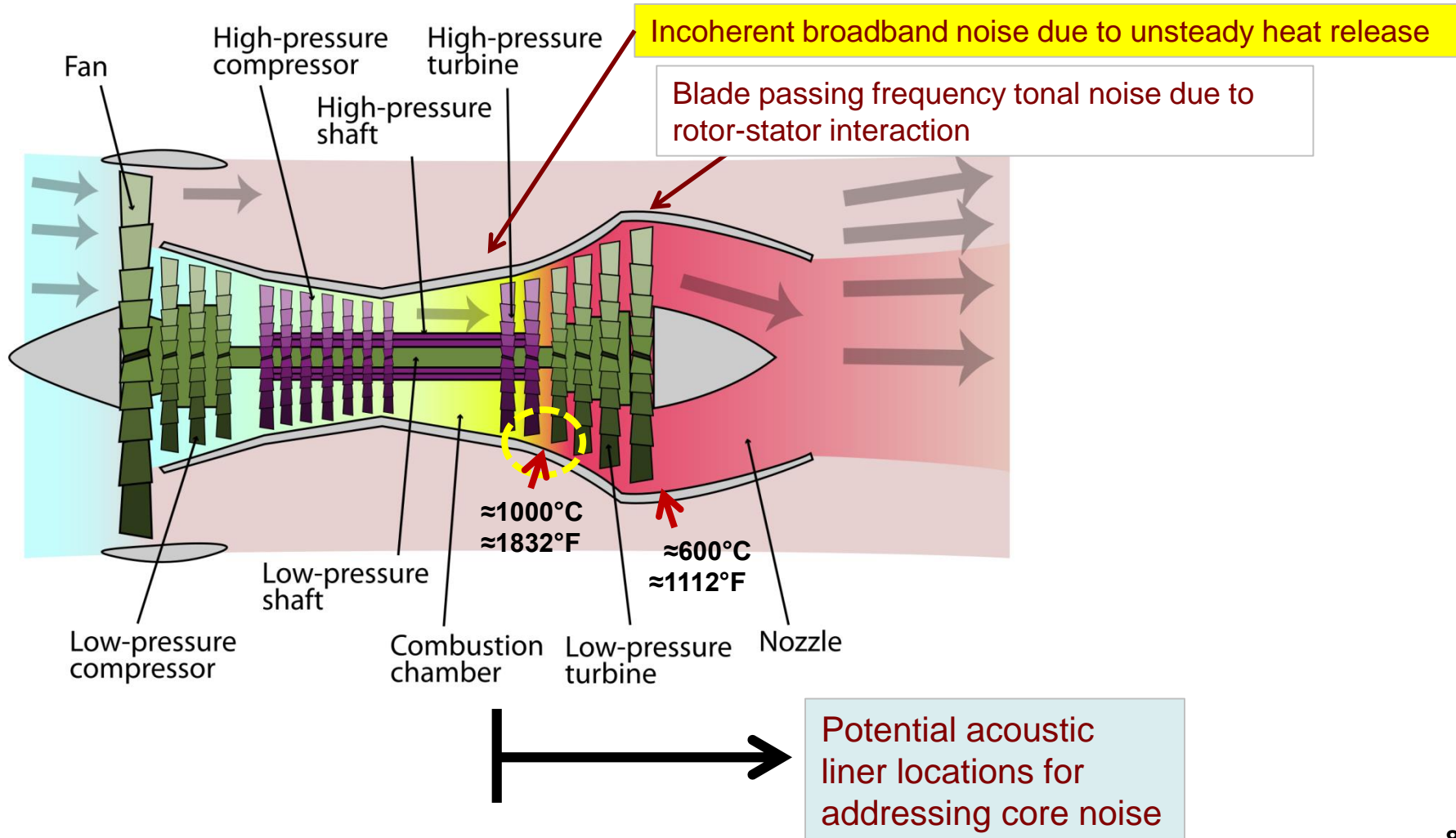
note that there is less room for core noise liners



# Core Noise Sources – Combustor and Turbine Noise

## ... Potential Acoustic Liner Location(s) To Be Determined

**Primary Goal:** develop an acoustic liner capable of reducing broadband core noise in a hostile internal engine environment







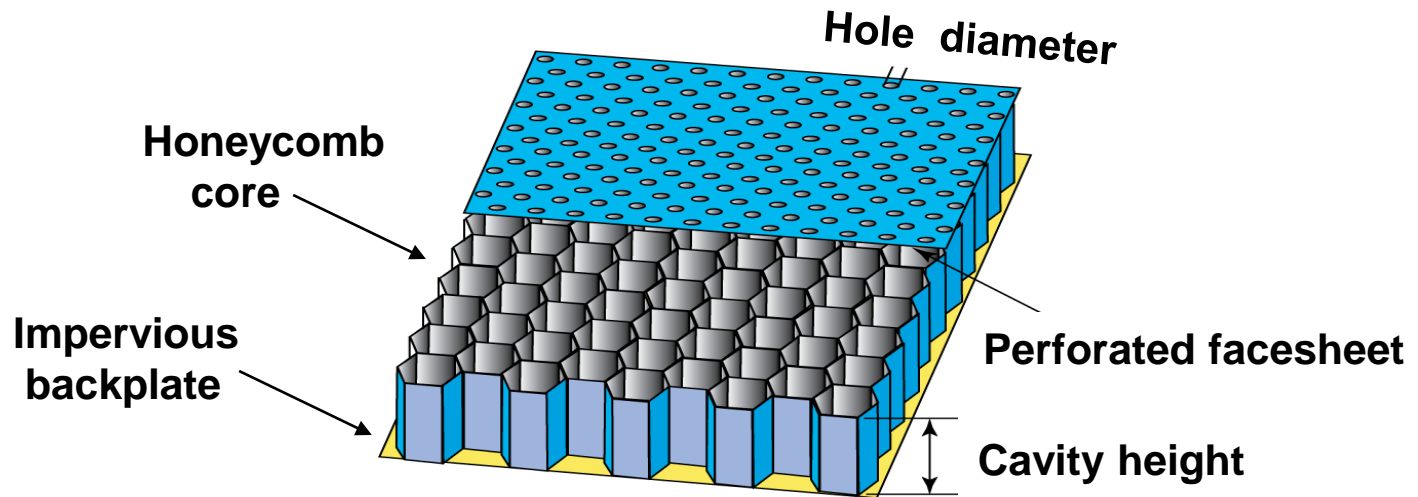
# Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

## Goals

- A lightweight, durable liner capable of reducing core noise over the frequency range of 400-3000 Hz, toward achieving NASA's noise reduction goals.
- Minimize the size of the liner. This is a significant concern in the core region of the engine, where the volume available for an acoustic liner is limited.

# Conventional, Passive Liner Treatment

## Conventional, passive liners:



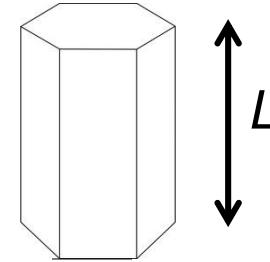
- Hexagonal or honeycomb geometry is of strong interest due to the improved strength that it provides.
- The cell cavity height and width control the frequency at which maximum absorption occurs.



# Quarter-Wavelength Resonator

The frequency that is absorbed by a quarter-wavelength resonator (e.g., a liner cell) is defined by:

$$f = \frac{c}{4L}$$



$f$ : frequency in Hertz (Hz) where maximum absorption occurs

$c$ : speed of sound in meters per second (m/s)

$L$ : length of the cell in meters (m)

**Example:** At 1112°F (600°C)—  
and  $c = 592$  m/s\*:

for  $L = 5$  cm,  $f = 2962$  Hz

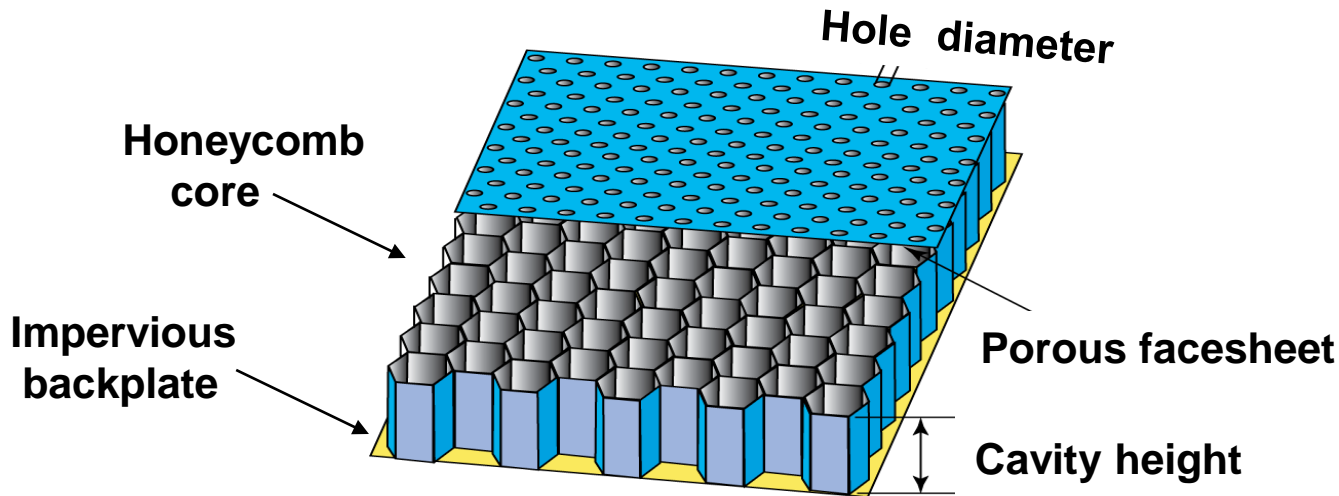
→ for  $L = 30$  cm,  $f = 494$  Hz

**frequency  
range of  
interest**



# Conventional, Passive Liner Treatment

## Conventional, passive liners:



- **Limitation:** Acoustic absorption spectra: characterized by a **single peak at the system resonance frequency and its odd harmonics** with significantly reduced absorption at other frequencies.



# Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

## Approach

- Pursue **alternate CMC acoustic liner geometries** that avoid the problems associated with conventional liners (that are based on honeycomb sandwich structures where all of the cells have a similar length).
- Initial approach that was investigated built upon an existing oxide/oxide CMC conventional liner manufactured by ATK COI Ceramics, Inc.





# Potential Advantages to Using Ox/Ox CMC Liner(s)

- In comparison w/uncoated SiC/SiC or SiC/SiNC CMCs, Ox/Ox CMC materials should:
  - provide better environmental stability from 482 - 982°C (900 - 1800°F), and
  - lower thermal conductivity (which could minimize heat flow to surrounding structures).
- Oxide fibers are relatively inexpensive (compared to SiC fibers).
- The density of a candidate Ox/Ox composite is  $\approx 2.8$  g/cc (AS-N610) vs. 8.4 g/cc for IN625, potentially offering component weight reduction and reduced fuel consumption.



# Oxide Fiber/Oxide Matrix CMCs: Properties/Max. Use Temperature

## Candidate CMCs—for fabrication of acoustic liners

Property	AS-N312	AS-N720	A-N720	AS-N650	AS-N610
→ Composite Density (gm/cc)	2.30	2.60	2.73	2.80	2.83
Nominal Fiber Volume (%)	48	45	45	39	51
Open Porosity (%)	24	25	25	25	25
RT Tensile Modulus (GPa)	31	76	70	96	124
RT Tensile Strength (MPa)	124	220	169	261	365
Short Beam Shear (MPa)	9.0	14.3	12.5	-	15.0
→ Thermal Expansion ( $10^{-6}/^{\circ}\text{C}$ )	4.8	6.3	6.0	8.0	8.0
→ Maximum Temperature ( $^{\circ}\text{C}$ )	650	1100	1200	1000	1000
Key: AS – Aluminosilicate matrix; A – Alumina matrix					

Various candidate oxide/oxide CMC materials available for use from 600 - 1200°C

Source: ATK COI Ceramics, Inc. website

<http://www.coiceramics.com/pdfs/3%20oxide%20properties.pdf>



# Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Core Noise

## Approach

- **Concept:**
  - Modify existing CMC honeycomb basic structure to **create a range of effective cell lengths that can reduce noise over a range of frequencies**
  - Various approaches previously demonstrated using other materials, **Refs. 7, 8.**



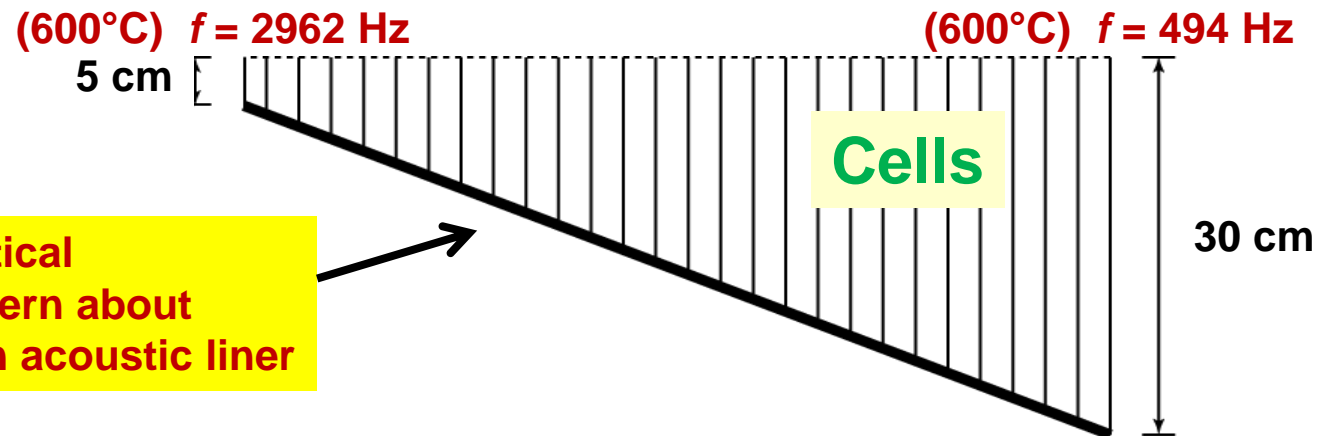
**Example:**  
**Ref. 8**

- Modeling will help guide the liner design. **Ref. 9**
- Demonstrate increased Technology Readiness Level (TRL) through development and testing of appropriate subelements / test articles.



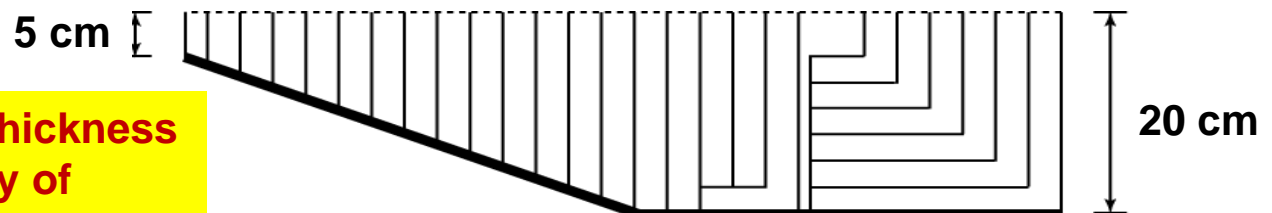
# Broadband Noise Reduction / Minimizing Liner Thickness

- Variable channel lengths** can provide noise reduction over a range of frequencies, because the cavity height controls the frequency at which maximum absorption will occur.



Unacceptable / impractical thickness—given concern about volume available for an acoustic liner

- Changing the configuration of the channels** by angling the cells or using curved or bent cells with the required effective length can significantly reduce the liner depth, while still providing nearly the same performance.

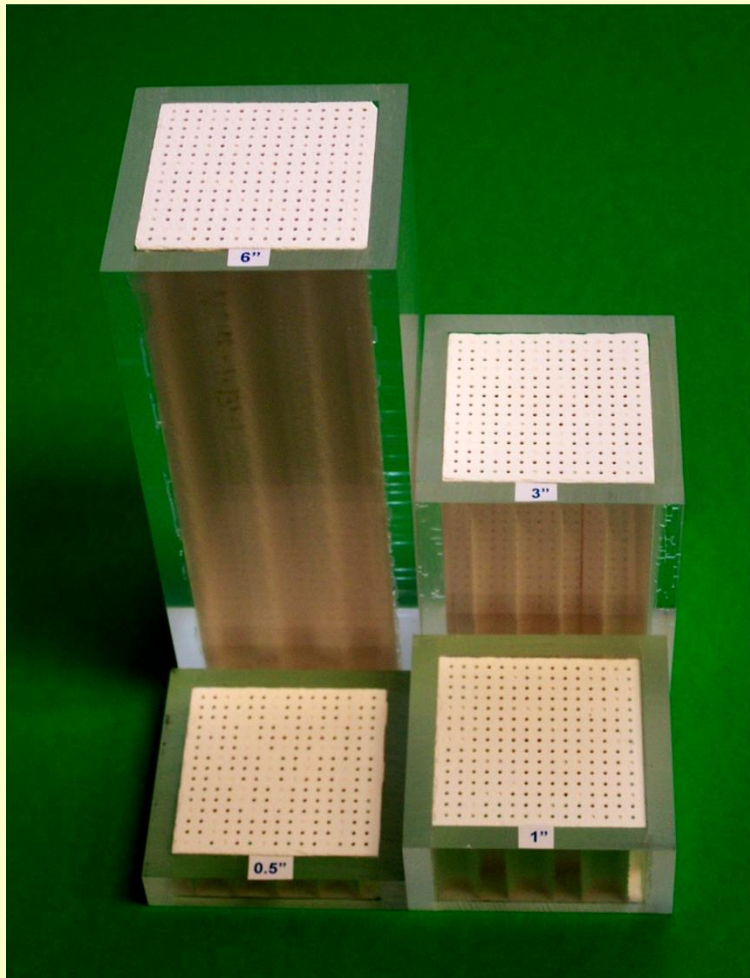


Significantly reduced thickness increases the feasibility of utilizing this type of liner

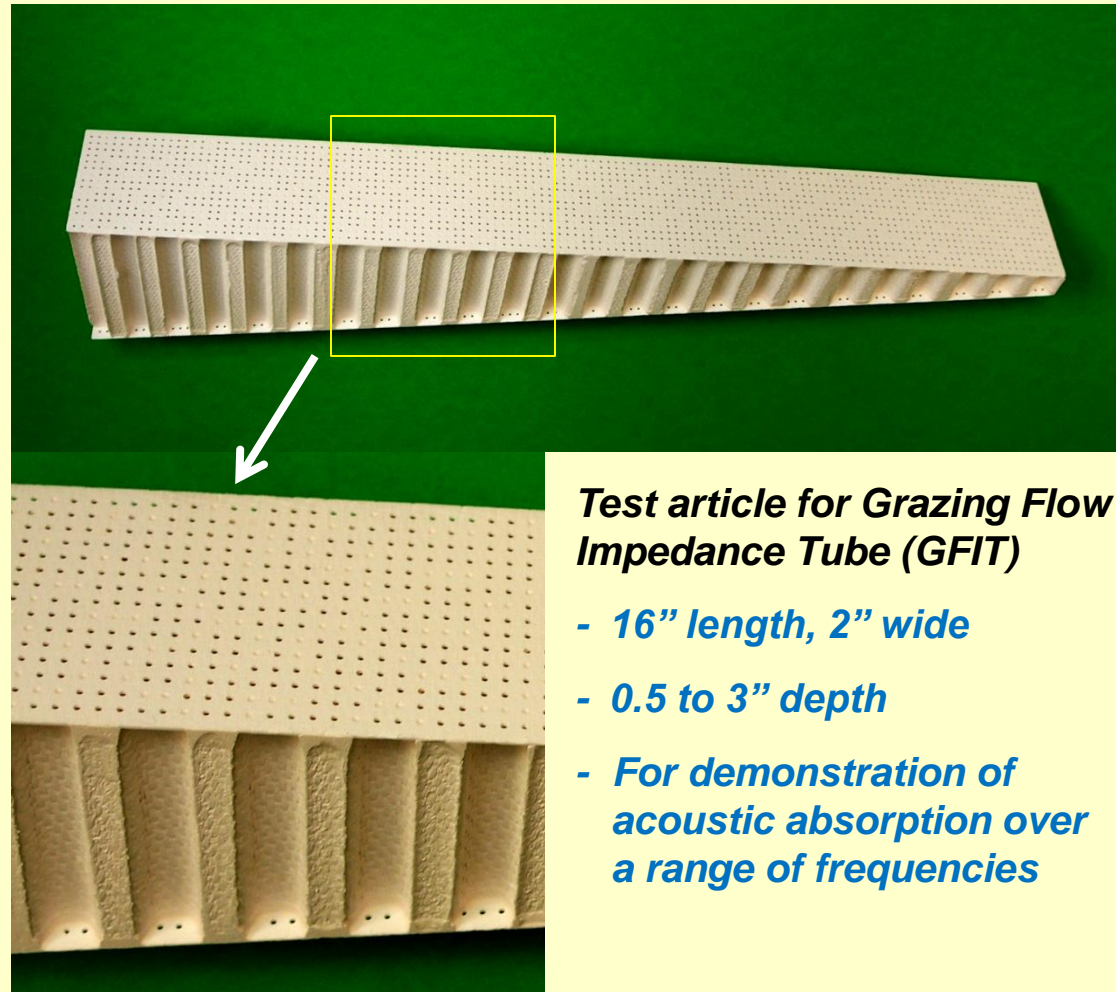


# Acoustic Performance Characterization

## CMC\* Test Articles\*\* for the NASA LaRC Acoustic Liner Test Facilities



**Test articles for Normal Incidence Tube (NIT) - 0.5", 1", 3", and 6" depth (2 x 2 " facesheets)**



**Test article for Grazing Flow Impedance Tube (GFIT)**

- 16" length, 2" wide
- 0.5 to 3" depth
- For demonstration of acoustic absorption over a range of frequencies

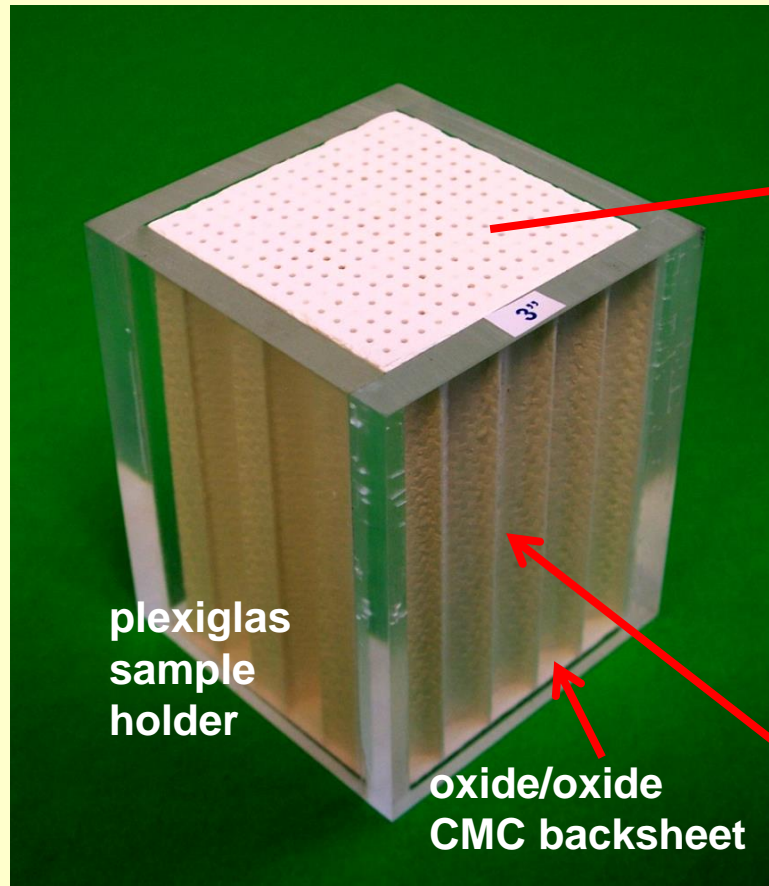
\* CMC (ceramic matrix composite)  
\*\* Fabricated by COI Ceramics, Inc.





# Acoustic Performance Characterization

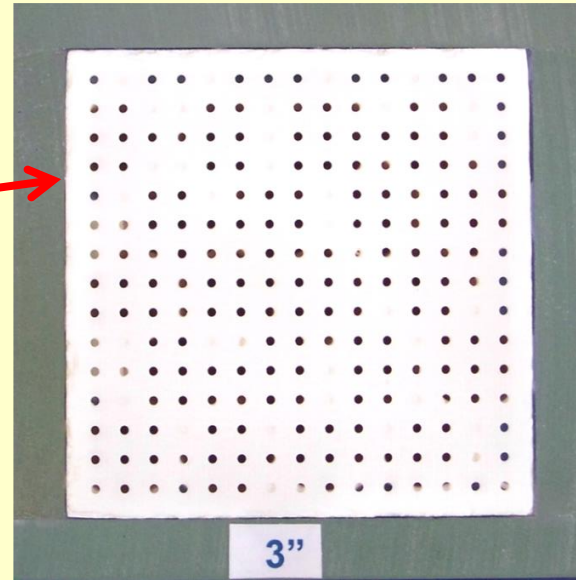
## CMC Test Article for the NASA LaRC Normal Incidence Tube (NIT)



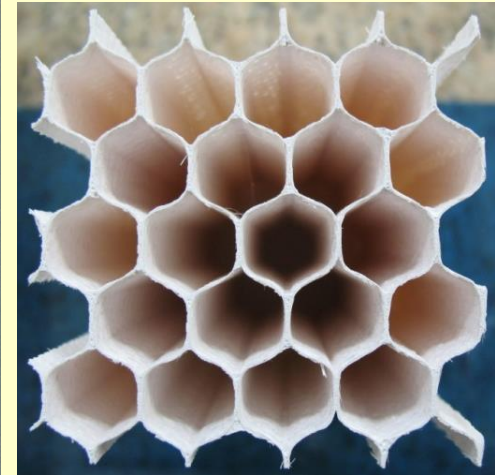
plexiglas  
sample  
holder

oxide/oxide  
CMC backsheet

**3" depth NIT test article\*\***



**2 x 2" perforated  
oxide/oxide  
CMC\* facesheet**



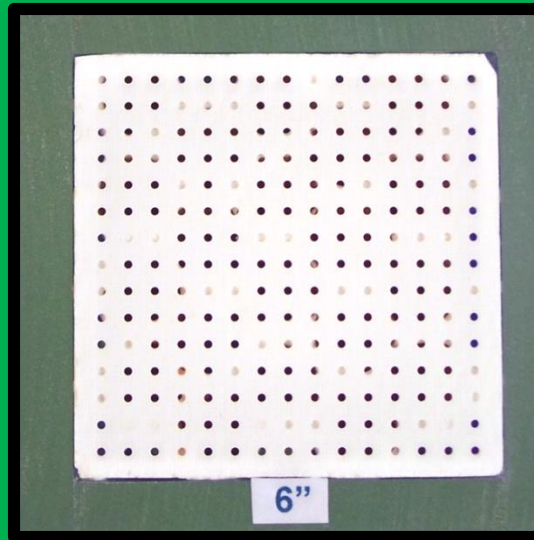
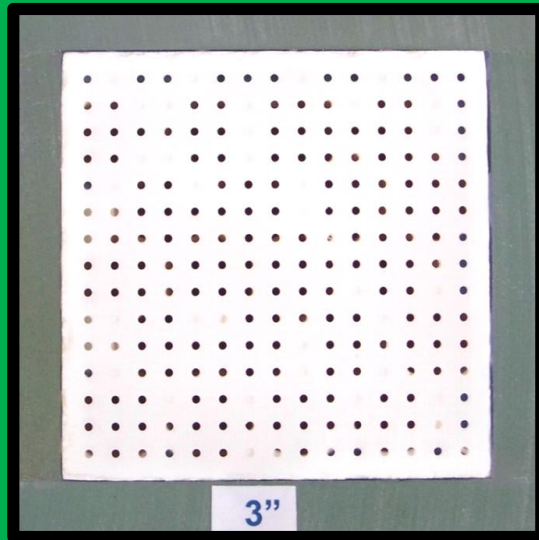
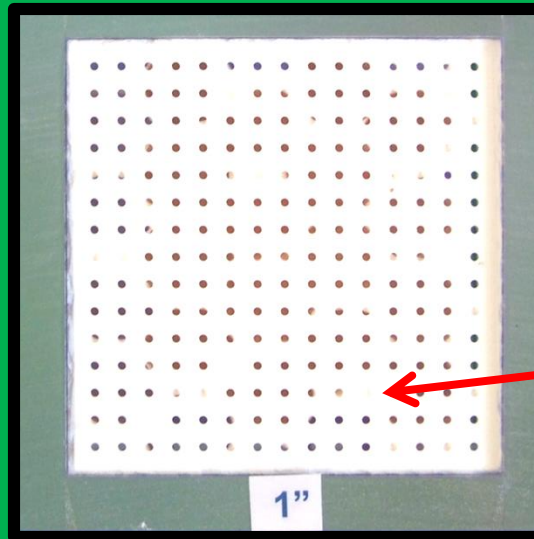
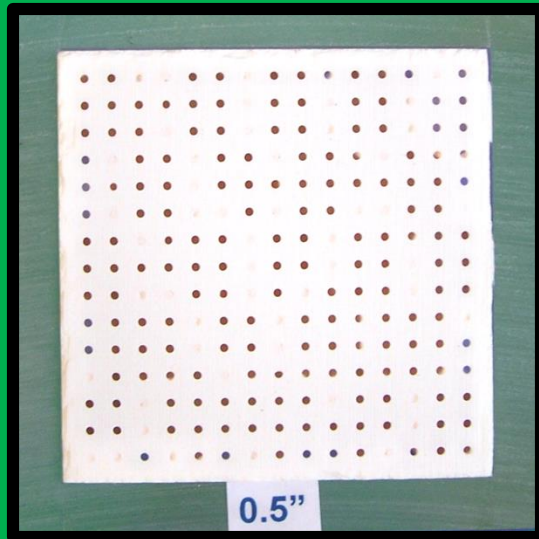
**oxide/oxide CMC  
honeycomb core**

\* CMC (ceramic matrix composite)  
\*\* Fabricated by COI Ceramics, Inc.



# Acoustic Performance Characterization

## CMC\*\* Test Articles for the NASA LaRC Normal Incidence Tube (NIT)



**Top View—  
Perforated oxide/oxide  
CMC facesheets**

- Holes spaced 0.125" apart
- Full or partial blockage of holes where facesheet bonded to CMC honeycomb core

**\*\* Fabricated by COI Ceramics, Inc.**



# Initial Evaluation of CMC Acoustic Liner

## NASA LaRC Normal Incidence Tube Characterization

(Ref. 6, 10)

### OBJECTIVES

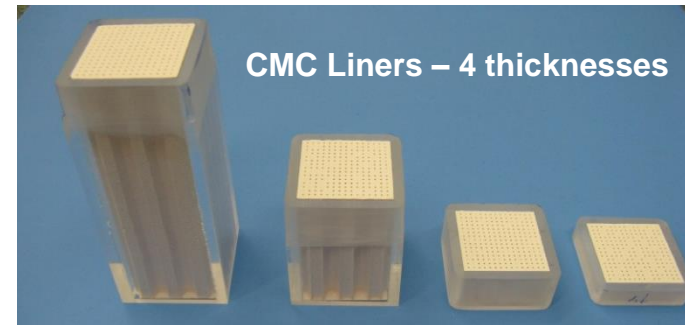
- Characterize basic CMC acoustic liner samples.
- Evaluate the conventional impedance prediction model over a realistic range of frequency and impedance spectra, to assess the effects of CMC porosity on acoustic performance.

### RESULTS

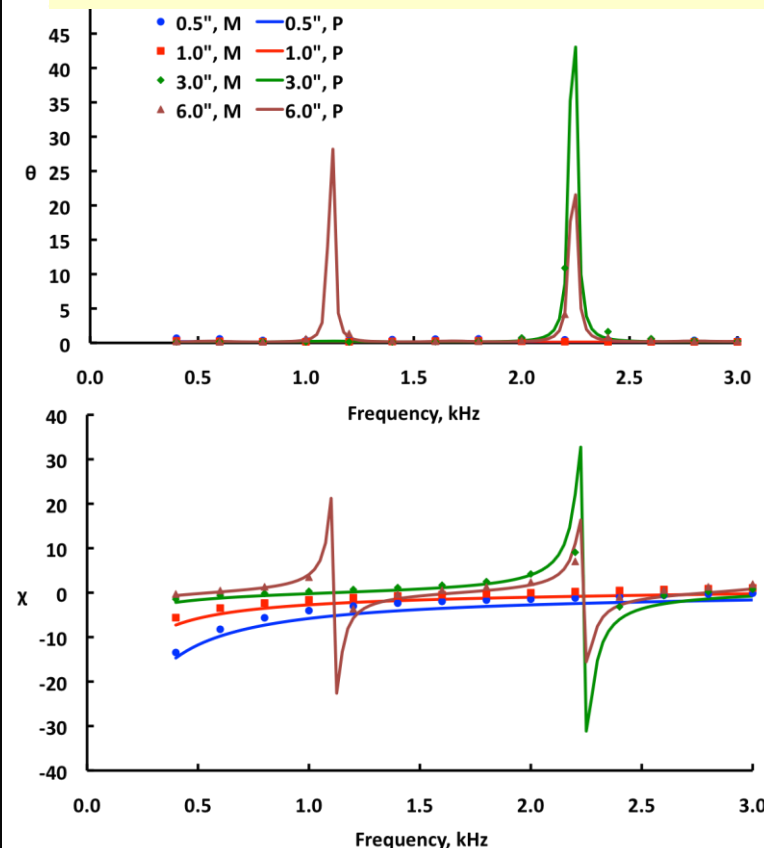
- The results were used to evaluate the prediction model over a realistic range of impedance spectra.
- Excellent agreement between the measured and predicted impedance spectra (**resistance**,  $\theta$ , and **reactance**,  $\chi$ ) was observed for this test condition (no flow, 140 dB).

### SIGNIFICANCE

- Impedance prediction model used for conventional liners is sufficient for use with the CMC structures and it was used to design a broadband CMC liner for Grazing Flow Impedance Tube evaluation.



Measured vs Predicted Impedance Spectra



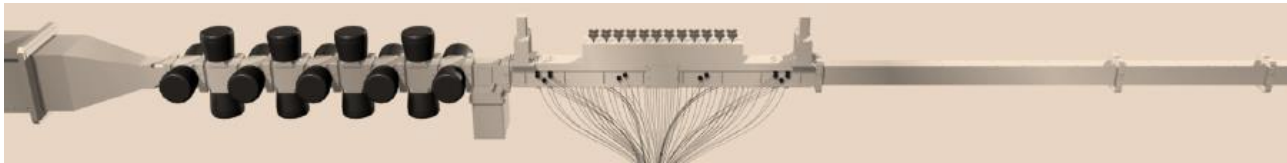


# Evaluation of CMC Acoustic Liner Test Article

## Grazing Flow Impedance Tube (GFIT) Characterization

### Testing

- The 16" long Ox/Ox CMC sandwich structure was tested in the Grazing Flow Impedance Tube (GFIT) in the NASA LaRC Liner Technology Facility ([Ref. 10](#)) to assess the effects of mean flow at ambient conditions.

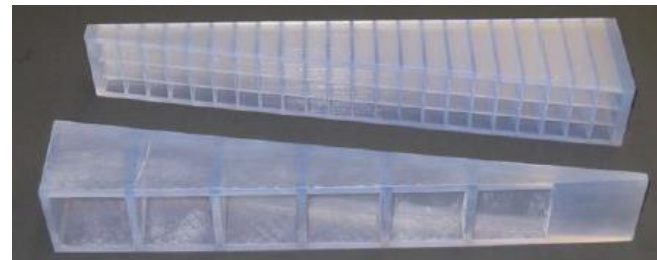


**GFIT**

- Comparison with a similar geometry plastic variable-depth liner fabricated via SLA (stereolithography) indicated that the material properties of the CMC liner have no significant effect on the resultant sound absorption.
- The potential for sound absorption with acoustic liners with varying impedance along the length of the liner was demonstrated.



**CMC**



**SLA**





# CMC Acoustic Liner Development—Concluding Remarks

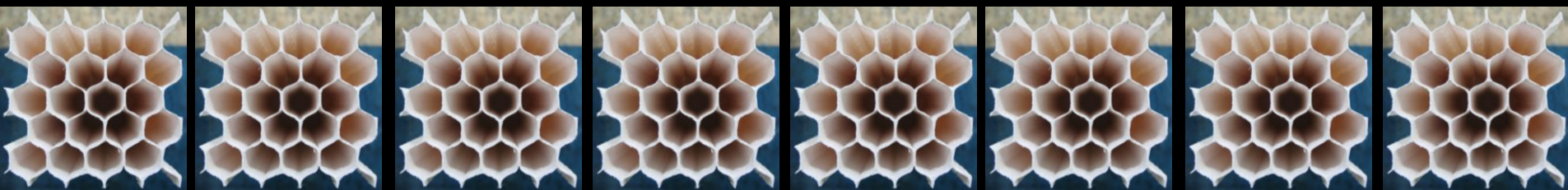
- Ox/Ox CMCs seem to be suitable candidate materials for core noise liners, based on initial acoustic testing at room temperature.
- Concepts for increasing the effective cell height for lower frequency absorption while minimizing the overall liner height have been identified by NASA (bending the cells, interconnecting the cells, etc.).
- The performance of a CMC acoustic core liner can be optimized using improved NASA design tools that will help us reduce noise over a specified frequency range.
- In the near term, concepts of interest could initially be investigated by examining test articles made via stereolithography prior to obtaining CMC samples.
- Follow-on activities could include characterization of CMC test articles up to 6000 Hz and at higher T to further the development of the technology. **Goal: Testing under increasingly realistic aeroacoustic environments.**





# Acknowledgments

- J. Heidmann, NASA GRC (Cleveland, OH)
- J. Riedell, ATK COI Ceramics, Inc. (San Diego, CA)
- NASA LaRC Liner Technology Facility





# References

- 1) "Core Noise—Increasing Importance," Lennart S. Hultgren, NASA ARMD Fundamental Aeronautics Program Technical Conference, Cleveland, OH, March 15-17, 2011.
- 2) "Core Noise Reduction," Lennart S. Hultgren, Acoustics Technical Working Group Meeting, Hampton, VA, October 18-19, 2011.
- 3) "Core-Noise Research," Lennart S. Hultgren, NASA ARMD Fundamental Aeronautics Program Technical Conference, Cleveland, OH, March 13-15, 2012.
- 4) "Core Noise: overview & upcoming LDI combustor test," Lennart S. Hultgren, Acoustics Technical Working Group Meeting, Hampton, VA, October 23-25, 2012.
- 5) "Liner Technology Research Progress," Michael G. Jones, Acoustics Technical Working Group Meeting, Hampton, VA, October 23-25, 2012.
- 6) "Compact, Lightweight, Ceramic Matrix Composite Based Acoustic Liners for Reducing Subsonic Jet Aircraft Engine Noise," J. Douglas Kiser, Michael G. Jones, Christopher J. Miller, Lennart S. Hultgren, and Joseph E. Grady, Proceedings of the 37<sup>th</sup> Annual Conference on Composites, Materials, and Structures, Cocoa Beach / Cape Canaveral, FL, Jan. 28-31, 2013.



# References

- 7) “Novel Applications of Acoustic Liners”, Michael G. Jones, ARMD Fundamental Aeronautics Program Technical Conference, Cleveland, OH, March 15-17, 2011.
- 8) “Development and Validation of an Interactive Liner Design and Impedance Modeling Tool”, Brian M. Howerton, Michael G. Jones, and James L. Buckley, 18<sup>th</sup> AIAA/CEAS Aeroacoustics Conference (33<sup>rd</sup> AIAA Aeroacoustics Conference), Colorado Springs, CO, June 4-6, 2012. AIAA 2012-2197
- 9) “Parallel-element liner impedances for improved absorption of broadband sound in ducts,” Tony L. Parrott and Michael G. Jones, Noise Control Eng. J. 43 (6), 1995 Nov-Dec.
- 10) “Evaluation of a Variable-Impedance Ceramic Matrix Composite Acoustic Liner,” Michael G. Jones, Willie R. Watson, Douglas M. Nark, and Brian M. Howerton, [20th AIAA/CEAS Aeroacoustics Conference](#) Atlanta, GA



# Appendix

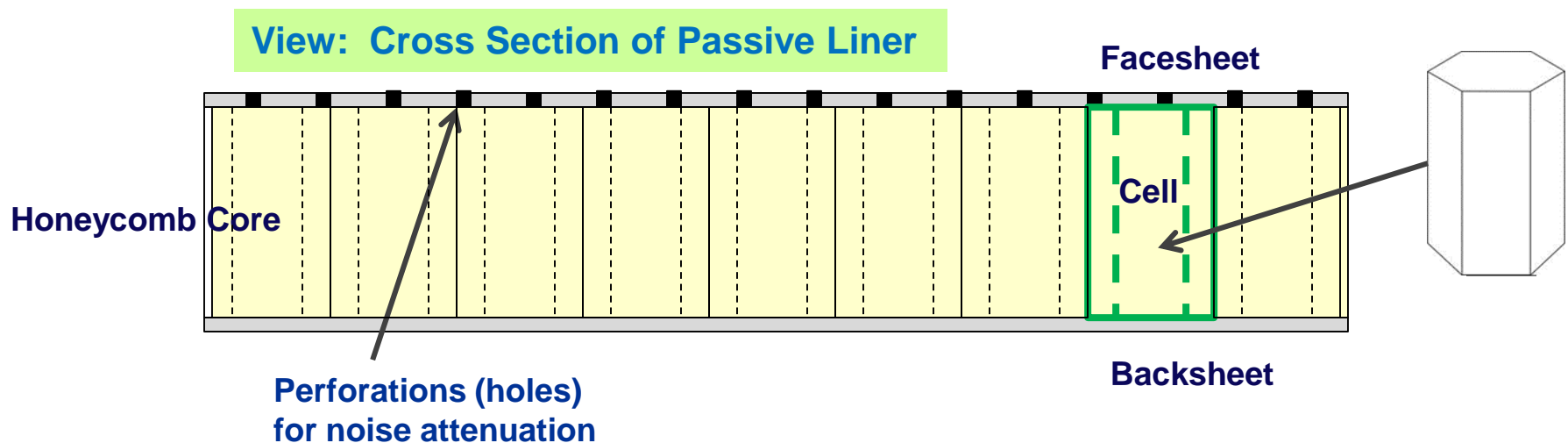
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# Conventional Liner Architecture

## Influence of Geometry/Structure on Performance

- The cell cavity height and width control the frequency at which maximum absorption occurs.
- Facesheet geometry (i.e., thickness, hole diameter, and porosity) controls the amount of acoustic absorption that will occur.
- Increased facesheet thickness can contribute to noise reduction and provide increased strength and impact resistance.
- However, increased facesheet thickness also increases the weight of the liner, as does increased liner depth.

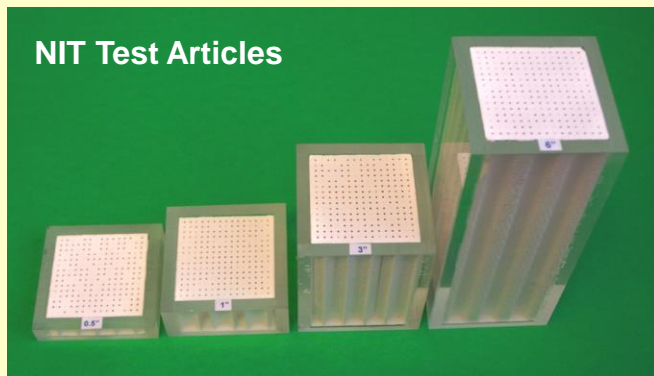






# Ox/Ox CMC Honeycomb Sandwich Structure Test Articles

- ATK COI Ceramics, Inc. fabricated the following CMC (ceramic matrix composite) honeycomb sandwich structures with perforated CMC facesheets for acoustic testing:
  - Four oxide/oxide 2 x 2" facesheet samples with different cell lengths for acoustic attenuation characterization at NASA LaRC via Normal Incidence Tube (NIT) testing.
  - A 16" long oxide/oxide test article with cells ranging in depth from 0.5 to 3" (1.3 to 7.6 cm) for testing at NASA LaRC via Grazing Flow Impedance Tube (GFIT) testing.





# Acoustic Absorption via Helmholtz Resonator

- Used to reduce lower frequency noise.
- Volume of the cell/chamber is sufficiently large to allow absorption of the lower frequencies.
- **Limitation:** Can lead to insufficient volume available for liner components targeting the higher frequencies.

$$f = \frac{c}{2\pi} \sqrt{\frac{S}{VL}}$$

$f$ : frequency in Hertz (Hz) where maximum absorption occurs

$c$ : speed of sound in meters per second (m/s)

$L$ : thickness of the facesheet in m

$S$ : surface area of the orifice in m<sup>2</sup>

$V$ : volume of the air within the cell in m<sup>3</sup>